COMPARISON OF VERTICAL AERIAL PHOTOGRAPHIC AND GROUND CENSUSES OF STELLER SEA LIONS AT AÑO NUEVO ISLAND, JULY 1990–1993

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ABSTRACT

Counts of Steller sea lion (*Eumetopias jubatus*) pups and non-pups (adults and juveniles) from aerial photographs of rookeries at Año Nuevo Island between 1990 and 1993 were significantly higher than those made on the ground. Based on regression of natural logs of photographic counts versus year, the number of pups declined at a rate of -0.099/yr while non-pup numbers declined at -0.315/yr. Examination of ground count data for the same period revealed a significant decline in non-pups (-0.139/yr), but no trend was detected in the ground counts of pups. The regression coefficients from photographic and ground counts of non-pups did not differ significantly. Power analyses using the program TRENDS indicated that detectable rates of change in abundance from four annual surveys were much lower for counts of pups than counts of non-pups where sampling precision was based on fits to linear models.

Key words: Steller sea lion, *Eumetopias jubatus*, pups, non-pups, Año Nuevo Island, vertical aerial photo counts, ground counts, replicate surveys, trends in abundance.

Since the 1920s, biologists have experimented with several techniques for counting the number of Steller sea lions (*Eumetopias jubatus*) occupying rookeries at Año Nuevo Island, CA (Fig. 1, 2), but none have proven entirely satisfactory. Counts conducted from blinds or a foghorn house on the main island consistently underestimated the number of sea lions present, because most rookeries are located on outlying rocks that are only partially visible from these survey sites (Evermann 1921; Bonnot 1928, 1929, 1931, 1937; Orr and Poulter
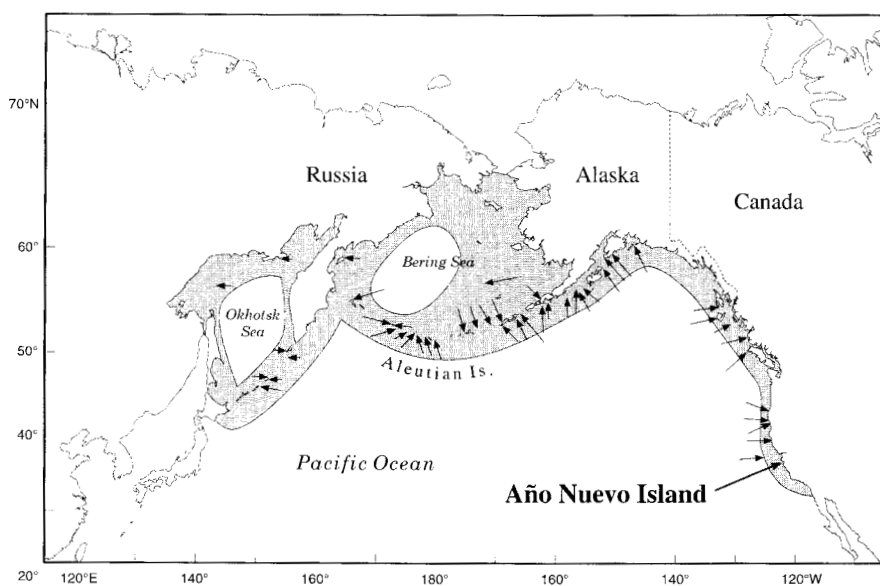
Figure 1. General range of Steller sea lions (stippled area) and location of Año Nuevo Island, the southernmost rookery for this species. Arrows indicate the major rookeries.
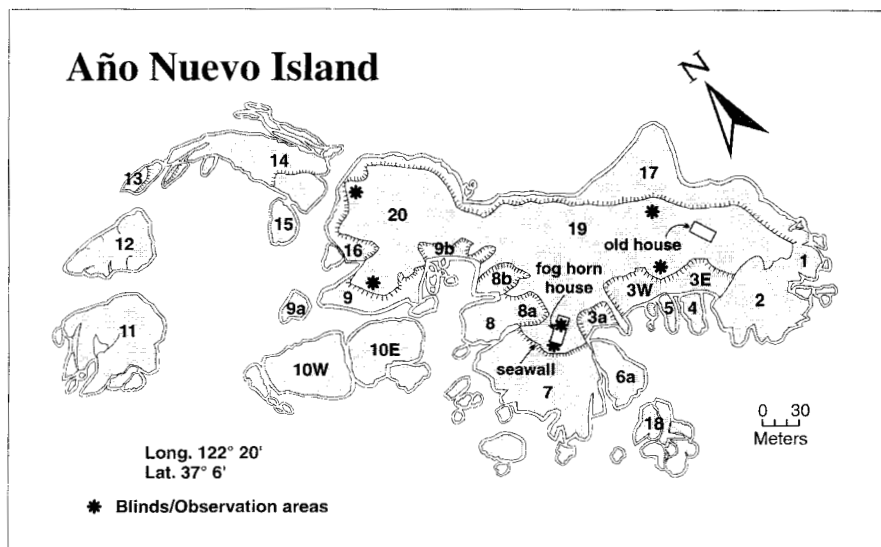

Figure 2. Map of Año Nuevo Island showing area numbers and blind/observation locations. Areas 9–12 refer to pupping areas in this report.

1965, 1967). Photographs have been taken from the main island to improve the accuracy and precision of counts of the sea lions that were visible to ground census teams, but underestimates caused by the topography and location of the rookeries still remained (Evermann and Hanna 1925). A few counts of pups were conducted after the adults and juveniles (non-pups) were driven into the water by biologists walking through the rookeries, but this census technique was so disruptive to the animals that it has not been practiced often at Año Nuevo (Orr and Poulter 1967, Gentry 1970). Oblique aerial photographs were taken of the rookeries in the 1940s and again in 1974 and 1983, and it appears that the counts of non-pups from these photographs were more accurate than counts conducted on the ground (Bureau of Marine Fisheries 1947, Bonnot and Ripley 1948, Le Boeuf *et al.* 1991). Counting of pups from these images was very difficult at best.

Despite problems of accuracy in the historical data, relative differences in the counts clearly indicate that the population of Steller sea lions has declined dramatically. From the early 1920s through the 1960s, ground counts of non-pups during the peak of the breeding season ranged from about 1,500 to 2,200 (Evermann and Hanna 1925, Orr and Poulter 1965, Gentry 1970). A steady decline in the counts began around 1970, leading to an 85% reduction in the breeding population by 1987 (Le Boeuf *et al.* 1991). Because of this decline, and the need to develop a noninvasive photographic census technique, a photographic survey used to monitor pinniped abundance at the California Channel Islands was tested at Año Nuevo Island.

Scientists at the Southwest Fisheries Science Center (SWFSC) began a vertical aerial photographic census program at Año Nuevo Island in 1990 in an attempt to improve the precision and accuracy of the counts of Steller sea lions at this site and to determine whether pups could be counted from the photographs. In this report we present the counts of pups and non-pups from these photographs, compare them with ground census results, and examine the trends in abundance derived from the two data sets from 1990 to 1993. We also conducted power analyses to determine the rates of change in abundance that are detectable with counts of pups and non-pups using vertical aerial photographs and ground observer counts.

METHODS

The photographic census flights were scheduled for early to mid-July when >95% of pupping is complete and the number of non-pups hauled out is also near its peak (Withrow 1982, Bigg 1985). On 11 July 1990, 26 July 1991, and 8 July 1993, we photographed the island near midday in a series of passes at altitudes ranging from 180–190 m. In 1992, we completed three photographic missions over the island. Two flights were approximately one hour apart on 7 July, and the third flight was completed by midafternoon on 8 July. The survey altitude was the same as in other years.

The photographs were taken vertically with a medium-format (126-mm, 5-in.) KA-45A reconnaissance camera that was mounted in a light twin-engine

aircraft. This camera has a medium focal length (152-mm, 6-in.) lens and combines fast shutter speeds, rapid cycle rates, and forward image motion compensation that significantly improve resolution at low altitudes. Camera cycle rate was adjusted to ensure that adjacent photographs overlapped by at least 80%, so individual animals could be seen on at least four frames. Kodak Aerochrome MS 2448 color transparency film was exposed through a haze filter for all of the photographs used in this study. An enlarged black and white photograph of one of the rookery areas is shown as an example (Fig. 3).

Photo counts—The aerial photographs from each mission were independently examined by three individuals experienced in counting pinnipeds in the field and from photographs. Counts were made by viewing the color transparencies with a variable power microscope mounted above a light table. Clear acetate sheets were placed over the images, and individual Steller sea lions (adult males and females, juveniles, and pups) were marked with colored pens. After all the animals on a frame were marked and tallied with hand counters, the acetate was moved to the adjacent overlapping frames and the marks were checked for errors. Thus, the final count for an area was based on examination of three or four photographs. Counts were recorded according to island areas designated by Orr and Poulter (1965, Fig. 2). When counts were made from the images of the three 1992 photographic missions, readers waited two to three days between counts from each mission. To ensure that readers were not affected by their previous count totals, hand counters were covered with tape until area counts were completed.

Ground counts—Ground counts were conducted using binoculars and spotting scopes from various vantage points on the main island, at elevations ranging from 0 to 6 m above the rookeries (see Fig. 2). In some cases the sea lions were counted from distances in excess of 100 m. The ground observers recorded the number of animals in each area, as done from the aerial photographs. Ground counts were conducted just prior to the aerial flight in 1990 and one day before the 1991 flight. In 1992 the rookery areas were censused from the ground on the flight days, two hours prior to the first flight on 7 July and one hour after the photo mission on 8 July. An additional ground count was conducted near midday on 9 July. In 1993 ground counts were conducted on three consecutive days, with the last census completed two hours prior to our midday flight on 8 July.

Analytical methods—Statistical tests were conducted on data taken from rookery areas, defined here as sites including both adult females and pups (areas 9–12, Fig. 2). We restricted our analyses to areas 9–12 because we were testing two different sampling systems on rookeries, and it is difficult to count animals in multispecies areas, as many California sea lions primarily use the non-rookery beaches at Año Neuvo. In our analyses we divided the Steller sea lions into two groups—pups and non-pups. Trends in abundance were estimated from linear regressions of the natural log-transformed counts for these groups (Eberhardt and Simmons 1992). Because the counts were made independently, we used all the counts from each year, rather than the means of the counts, in our regressions (Sokal and Rohlf 1981).

We conducted power analyses to estimate the rate of change in Steller sea

Figure 3. Enlarged area 12 (midsection) from a vertical aerial photograph taken from 180 m (600 ft). Pups are visible as the smallest, darkest animals.

lion abundance that could be detected with four annual surveys of pups and non-pups. For these analyses we used the program TRENDS which performs the power analysis for detecting trends in abundance using linear regression as described in Gerrodette (1987, 1991, 1993). We set $\alpha = 0.05$, $\beta = 0.90$, and

we assumed that the precision (coefficient of variation = CV) of the counts did not vary with abundance and that the nature of change in abundance was multiplicative (exponential model) and used the t distribution to estimate the power of the linear regressions. Link and Hatfield (1990) argued that Gerrodette's (1987) use of the standard normal distribution to compute power was inappropriate in situations where sample sizes were small and only the deviations of the sample points from the regression were used to estimate error variance. Because we had information from replicate surveys to provide data on the precision of our assessments, we thought that the use of the t might be overly conservative, and we repeated these analyses using the standard normal distribution.

We calculated the final factor in the TRENDS model, sampling precision, in two ways. First, we used the CV from the replicate aerial surveys in 1992 and the replicate ground surveys in 1992 and 1993 to estimate the precision of each census technique. This statistic estimates the variability associated with counting pups and non-pups from the aerial photographs and from the ground. For non-pups, the number ashore may also vary between replicates, and this variance contributes to the estimate of precision. We also calculated the precision of the counts from the residual mean-squared error, divided by the mean of the counts, from linear regressions of the counts over the four annual surveys. This statistic includes the variation associated with counting and also the year to year variability in the counts that is not explained by the linear model.

RESULTS

Count comparisons—Counts from aerial photographs were significantly higher than those made from the ground for both pups (t-test, $P < 0.001$) and non-pups ($P = 0.005$, see Fig. 4). The difference in counts from the two sampling techniques was largest for counts of pups. Counts of non-pups from the main island and rocks surrounding the rookeries did not indicate that the reduction in counts on the rookeries was the result in a shift of adults and juveniles to other nearby haul-outs. These counts of non-pups from non-rookery areas were not included in the analysis due to the high variability of counts from photographs among these areas. Many California sea lions hauled out on non-rookery areas, and it was more difficult to differentiate Steller sea lion juveniles within the mixed aggregations. Photographic counts of the individual readers are presented in Table 1.

Regressions of natural log-transformed counts of pups and non-pups from aerial photographs indicated a significant decline over the four years of this experiment, while only the natural log-transformed counts of non-pups from the ground showed a significant trend (Fig. 5). Instantaneous rates of decline for photographic counts of pups and non-pups were -0.099 (SE = 0.010) and -0.315 (SE = 0.137) respectively, while ground counts of non-pups declined at a rate of -0.139 (SE = 0.137). Comparison of the slopes of the photographic and ground counts of non-pups revealed no significant difference between these two rates of decline ($P = 0.668$).
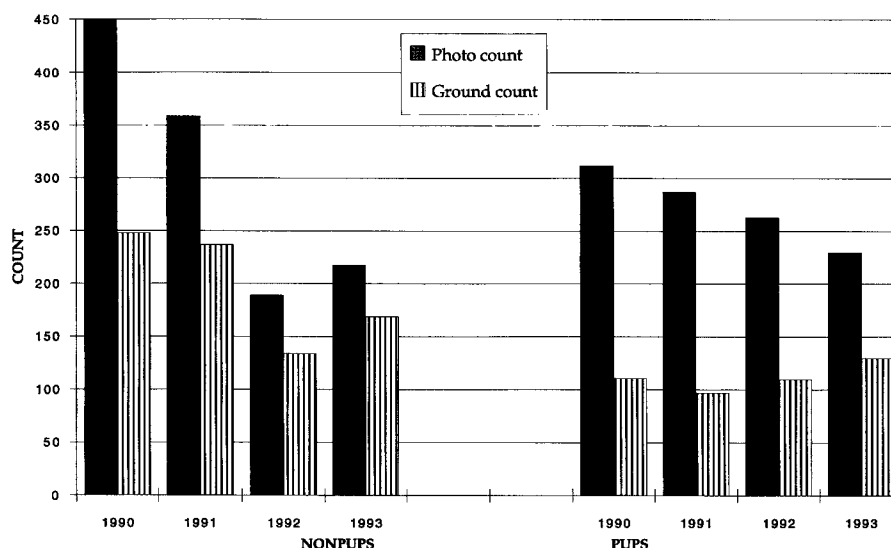
Figure 4.   Counts of Steller sea lions, rookery areas 9–12, at Año Nuevo Island.

Trend analysis—The CVs calculated from the 1992 replicate photographic surveys were significantly lower than those from the replicate ground surveys for pups ($F_{0.05(2),2,8}$ = 21.89), and lower, but not significantly, for non-pups ($F_{0.05(2),8,2}$ = 1.78). These differences were reflected in the calculated detectable rates of decline in abundance (Table 2). If we can assume that the numbers of pups and non-pups on the rookery areas did not change significantly over the period of the replicate surveys, then these results imply that whatever bias is present in the two census techniques is very consistent.

When we repeated these analyses, using the residual sum of the squares from linear regressions to estimate precision, we found that it had little effect on the predicted detectable rates of change from counts of pups (Table 2). The added variance contributed by the lack of fit for the non-pup counts increased the detectable rate of change by a factor of two for ground counts and four for photo counts.

DISCUSSION

We found that we could successfully extract very precise counts of Steller sea lions from vertical photographs of the rookeries at Año Nuevo Island. Our success was the result of a very high resolution photographic system and the gradual sloping topography of the island. Without overhanging cliffs, crevices, or boulders to obscure visibility from above, the sea lions, including the pups, were clearly visible in the images. Because of the steady decline of Steller sea lions at Año Nuevo Island, we decided not to conduct a drive count to test the accuracy of our counts. Invasive assessment techniques are probably inappro-

Table 1. Counts of Steller sea lions from aerial photographs during survey years 1990–1993, Año Nuevo Island. RDR = Reader, FLT = Flight.

	11 July 1990				26 July 1991				1992 Replicate flights FLT 1–7 July		
	RDR 1	RDR 2	RDR 3	Mean	RDR 1	RDR 2	RDR 3	Mean	RDR 1	RDR 2	RDR 3
PUPS	325	311	301	312	305	279	276	287	263	247	257
NON-PUPS	455	440	452	449	360	366	351	359	195	191	201

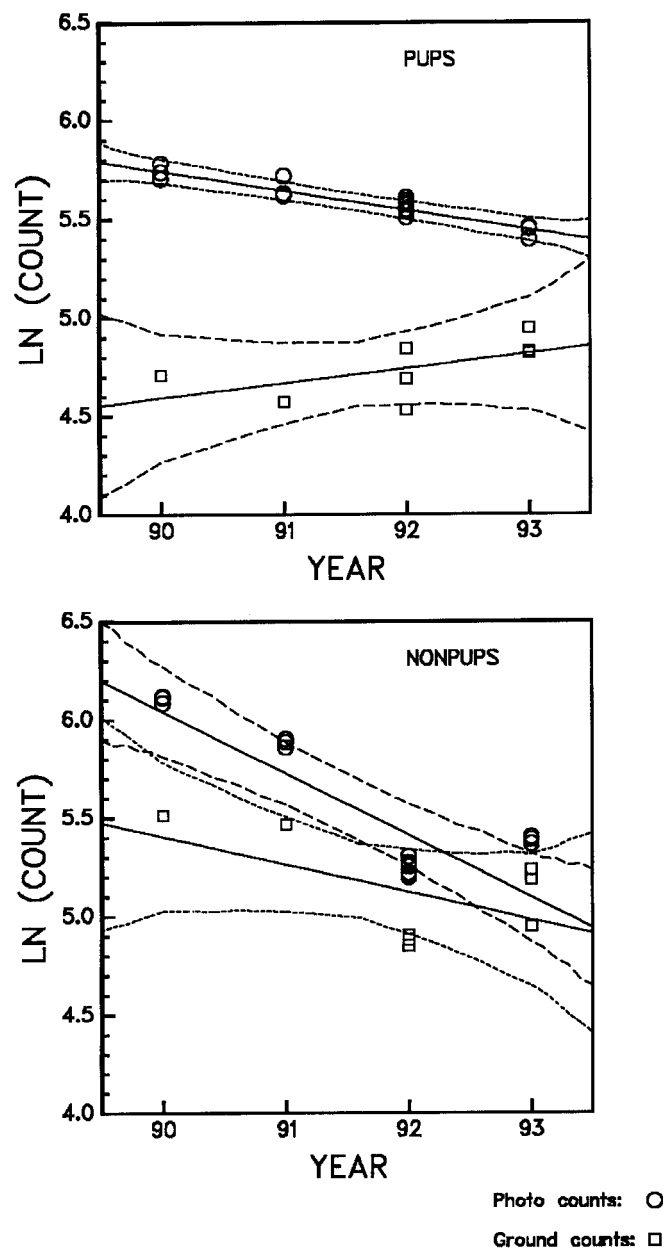|	1992 Replicate flights FLT 2–7 July			FLT 3–8 July				8 July 1993			
	RDR 1	RDR 2	RDR 3	RDR 1	RDR 2	RDR 3	Mean	RDR 1	RDR 2	RDR 3	Mean
PUPS	273	254	268	273	264	265	263	235	233	221	230
NON-PUPS	183	181	182	185	191	193	189	219	214	222	218

Figure 5.   Trends in abundance for Steller sea lions at Año Nuevo Island, based on linear regressions of natural log-transformed count data (○ denotes photo counts, □ denotes ground counts) for pups (above) and non-pups (below), showing 95% confidence bands about their respective regressions.

Table 2.   Trends analyses of the replicate survey data for photo and ground counts of pups and non-pups, showing coefficients of variation and the detectable annual declines in abundance over a four-year period for both methods.

Data source	CV replicates	CV regressions	Detectable annual decline in abundance in 4 yr	
			Replicates	Regressions
Pups-photo	0.033	0.037	.10	.11
Pups-ground	0.114	0.123	.29	.31
Non-pups-photo	0.036	0.193	.10	.44
Non-pups-ground	0.088	0.234	.23	.50

priate at this site, given the small changes in the population that can be detected with remotely sensed data.

The counts from the aerial photographs indicate that the Steller sea lion population at Año Nuevo Island continued to decline between 1990 and 1993. Counts of pups declined at a rate of about 10%/yr, which is higher than the rate of decline reported from aerial surveys between 1989 and 1994 in the Gulf of Alaska (7%/yr) and the eastern/central Aleutian Islands (3.6%/yr), in comparison with a slight increase of pup counts (1.7%/yr) in southeast Alaska (NMFS, unpublished data[1]). The rate of decline in our counts of non-pups was much more dramatic (about 31.5%) and was also much higher than the annual declines reported in the Gulf of Alaska and the eastern/central Aleutian Islands (8% and 2.2%/yr, respectively) from 1989 to 1994, with a small increase in counts of non-pups (1.3%/yr) in Southeast Alaska (NMFS, unpublished data[1]).

Unusual oceanic conditions probably contributed to the Steller sea lion decline at Año Nuevo Island. During the early and late months of 1992, the waters near the California coast were uncommonly warm due to the effects of an El Niño (Hayward 1993). Possibly, as has been shown with California sea lions during El Niño conditions (DeLong *et al.* 1991, Huber 1991), this oceanographic condition affected Steller sea lion haul-out patterns of non-pups, and pup production to a lesser degree. Both ground and photo counts of non-pups were slightly higher during the 1993 surveys.

The results of our TRENDs analyses illustrate the difficulty in monitoring trends in abundance for this species from counts of non-pups. Although non-pups are large and easier to count, their numbers on shore represent some percentage of the population which appears to fluctuate in an unpredictable manner from day to day (Calkins and Pitcher 1982). Counts of pups are clearly a better choice, especially when they can be obtained without disturbance to the breeding aggregations. It should be noted, however, that density-dependent mortality can influence trends interpreted from counts of pups, depending on when the counts are conducted (Berkson and DeMaster 1985).

Acknowledgments

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